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RESEARCH ARTICLE

Morphological and physico-chemical properties of Cryosoils in the Bulgarian antarctic base on Livingston island, Antarctica

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Abstract

Under the global climatic changes and anthropogenic impacts on the environment, information about characteristics and specific features of soils in remote regions as Antarctica is valuable and could be used as references. This study focuses on the analyses of original data about the physico-chemical composition and micromorphological structure of Cryosols, collected in 2019 from the sampling area of the Bulgarian Antarctic Base "St. Kl. Ohridski" located on Livingston Island, Antarctica. The studied Cryosols are moderately acidic with slow and incomplete transformation of organic residues. The organic carbon content is low, except for soils formed under the influence of an ornithogenic factor. The mezo- and micromorphological observations show a predominance of the mineral phase, weakly affected by weathering processes. Many soil pores and voids are observed, which facilitates water-air and intra-soil exchange during the short Antarctic summer. The analyses showed an evidence for the connection of the processes of soil formation of Cryosols in the region with the pulsating degradation of the glaciers.

Keywords

Cryosols, soil properties, micromorphology, Livingston island, Antarctica

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Introduction

Antarctica is the last continent discovered and is not yet fully explored. The nature of this vast space is largely devoid of human impact. This makes the region an ideal site for research on climate changes. Soils in the sensitive polar regions can be used as indicators of climate and environmental changes, due to the early process of soil formation and the ability to account for minimal alterations in their physical and chemical properties. The present analysis is conducted on Livingston Island (South Shetland Islands archipelago) and studies sites within the vicinity of the Bulgarian Antarctic base "St. Kliment Ohridski".

Livingston Island is part of the South Shetland Islands archipelago, Maritime Antarctica. The area of the island is 845 km^2 and only 10% is ice and snow free in the period of the short Antarctic summer. The island is formed from three structural terraces. The uppermost one, 2 km thick, is in fact crystallized andesite and basalt lava, mixed with sandstones and conglomerates. Three physio-graphical sectors can be distinguished on the island: eastern, covered by icebergs; central, characterized by high ice heaps and platforms; and western – plain-like almost without ice cover. The terrains from which the icebergs have withdrawn are covered by moraines (Sokolovska et al. 2015).

The meteorological conditions, landslides and especially – water and erosion, play a leading role in the formation of modern landscape forms in the study area. In the plain surfaces, the destroyed rock base mixes with tephra and creates fields with a typical perilatial grouping of the weathered material (Kenderova & Baltakova 2015). On slopes with western and southwestern exposure, the weathering processes of the rocks develop with greater intensity. A typical relief-forming process, characteristic for the steep slopes of the Bulgarian beach is cryosolifluction (gelifluction) and is observed in slopes over 10° in the area of the chapel "St. Ivan Rilski" and the Bulgarian beach (Kenderova & Baltakova 2015)

The formation and development of the soils in the studied area is related to the time of retreat of the glacier and the period during which the newly formed soil remains exposed. In turn, the soil formation process takes place in a permafrost environment (Oliva & Ruiz-Fernández 2017).

In the face of climate change, any information about soils is valuable. Considering that the first data on the soils on the territory of the Bulgarian Antarctic base on the Livingston Island were obtained 20 years ago, the need to conduct investigations on soils that are up to date is even stronger. This makes it possible to monitor the processes of entry, transformation, accumulation and mineralization of substances related to their balance in the soil cover. The aim of the present work is to expand the range of knowledge about the physico-chemical composition and micromorphological structure of Cryosols from Antarctica. The following tasks were completed:

1. Analysis of the mechanical composition of the soils;

2. Analysis of the newly obtained chemical parameters and content of organic carbon;

3. Analysis of the micromorphological composition and properties

Materials and methods

Study area

Soils from five locations were sampled for further humic substance isolation and investigation on the micromorphology of organic substances. All soils have top humus layers with high carbon content and distinguishable layers of suprapermafrost accumulation of organic matter. All studied soils are classified as Turbic Cryosols (Histic, Stagnic), according to the World Reference Base for Soil Resources (WRB) 2014.

The samples collected in the present study represent the soil micromorphology of the terrestrial ecosystems of Livingston Island, South Shetland Islands. The sampling was realized during the Antarctic summer season 2018/2019. All sampling sites are located in the vicinity of the Bulgarian Antarctic Base "St. Kliment Ohridski" (S 62°38'25.7", W 060°21'54.9") (Fig. 1).

Purposive sampling was conducted by considering the snow-free areas along the coastline of the island in terms of the geospatial characteristics and accessibility to the sites. The parent rock (sandstone, Mount Bowles formation – MBF) and weathering material, as well as the distribution of vegetation have been also considered as important indicators for soil organic matter (SOM) formation. All sites have been located with GPS coordinates in WGS-84 coordinate system.

Playa Bulgaria (PB1)

The sampling site is located in the south part of the Bulgarian beach on a hill formed by gabro and diorites (Hesperides composite pluton, MBF) on elevation of

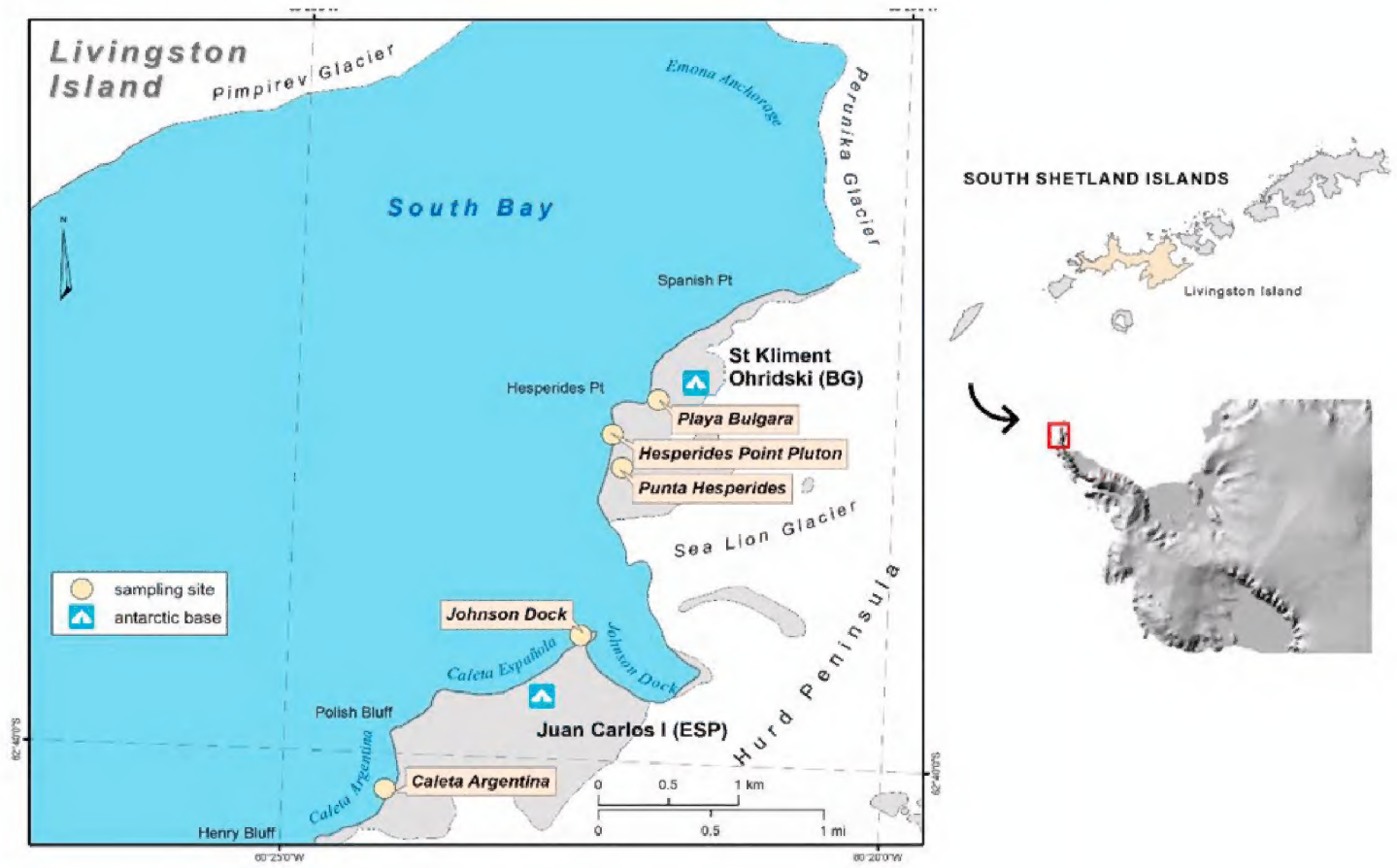

Figure 1. Study sites on Livingston Island

71 m a.s.l. The soil has a greyish-black colour 10YR 4/2 and two layers with varying depth can be distinguished. Location is covered by mosses, lichens and *Deschampsia antarctica* in between the rock sediments. Remnants are mixed and represent medium decomposed organic horizon (Fig. 2).

Figure 2. Sampling site PB1

Hesperides Point Pluton (HPP2)

The sampling location is situated on a small cove in the foothill of Hesperides hill (7 m a.s.l.) around 20 m inland (Fig. 3). Under a thick moss layer, the soil formed is reaching a depth of 2-3 cm and mixed with many remnants of mollusks (Patella).

Figure 3. Sampling site HPP2

Punta Hesperides (PUN-H1)

The sampling location represents plateau-like top of the Sea Lion Hill with present skua nests (50 m a.s.l.). It is located western of Sea Lion Lake (aka "Todorina buza" Lake) over a dense layer of lichen and mosses (Fig. 4).

Figure 4. Sampling site PUN-H1

Johnson Dock (JD1)

That place is a small, nearly closed bay in low tides. The terrain is rocky and on the south of the bay, the coast has cape-like shape (Fig. 5). The sample is collected on the second marine terrace at about 1 m a.s.l., which is covered by many marine and slope sediments.

Figure 5. Sampling site JD1

Caleta Argentina (CA1)

That place is a bay characterized by Papua penguin rockery (Fig. 6). In the past there was a vast penguin colony, but currently there are about 15-20 nests situated in the south part of the beach at about 2 m a.s.l. There are sporadically distributed *Deschampsia antarctica* tuffs and the terrain is also characterized with a solid cover of decomposed Antarctic green alga *Prasiola crispa* in post-ornitogenic environment.

Figure 6. Sampling site CA1

Soil analyses

The soil samples were collected in December 2018 from the top layer in all sites allocated with GPS coordinates in WGS-84 coordinate system. The soils samples were stored in small cardboard boxes to ensure the solid and untacked structure of the soil. All samples have been air-dried at room temperature in the laboratory of the Bulgarian Antarctic Base to reach an air-dry state. Later, in the premises of the Laboratory of Soil Science in Forest Research Institute – Bulgarian Academy of Sciences (FRI-BAS), Sofia, the samples were dried, weighted and sieved through 2 mm in order to proceed with further analyses.

The pH of soil and vegetation samples was measured by digital pH-meter Pracitronic in H_2O (soil:water ratio 2.5). All samples were analysed for total organic carbon by the Turin method and total nitrogen by the Kjeldahl method.

The total weight of the samples, as well as fine and coarse fractions were determined and calculated after dry sieving. Granulometric analyses of the sand, silt and clay size fractions was realized according to the standardized methods.

The morphology of the surface of the rock fragments and their chemical composition were studied with the use of a SEM CamScan MV2300 equipped with an energy dispersive detector in the laboratories of the Department of Applied Ecology at Saint-Petersburg State University. For the micro probe analysis, polished transverse sections of the rock (to a depth of 7 cm) were prepared and coated with gold film. The resulting smooth surfaces made it possible to examine the micromorphological features of the vertical differentiation of the soil fragments under the impact of biotic communities.

Results and discussion

In the Antarctic, the parent rocks are represented by eluvium and deluvium weathering products of igneous and metamorphic bedrocks, as well as volcanic sedi-

ments. It was revealed that the granulometric composition of Antarctic soils is mainly inherited from parent rocks. A general characteristic of the dispersion of Antarctic soils is the high content of skeleton (from 50 to 99%), although soils are found with a predominance of fine earth over the skeletal fraction (Abakumov 2010; Abakumov & Romanov 2013).

Table 1. Physical-mechanical characteristics of the studied soil samples of Livingston Island

Site	Soil type	Coarse fractions, %		Granulometry, %			Relative density, g/cm^3	Hygroscopic moisture,%
		>1mm	>3mm	silt	sand	clay		
				<0.01	>0.01	<0.001		
PB1	Cryosols Leptic	19.2	44.95	10.30	89.70	0	2.4	9.71
HPP2	Cryosols Histic Hyperskeletic	26.51	3.5	10.27	89.73	0	2.7	9.75
PUN-H1	Cryosols Histic Hyperskeletic	26.52	20.12	2.06	97.94	0	2.6	9.74
JD1	Cryosols Leptic Hyperskeletic	17.39	71.75	10.61	89.39	-	0.64	9.95
CA1	Cryosols Leptic Hyperskeletic	-	-	5.13	94.87	0	2.6	9.75

The mechanical composition of soils is inherited from soil-forming materials. A common property of the studied soils is the high content of skeletal fraction. In the Cryosols Leptic formed on the MDF formations and Cryosols Leptic Hyperskeletic (JD1) formed on the sedimentary materials slightly affected by the weathering process, this is clearly observed – respectively 64.15 – 89.14%.

The relative density of the soil varies slightly – between 2.6 and 2.7 g/cm^3 (Table 1). Very low density is established in the site JD1 due to the higher content of coarse fraction and the early state of weathering process. The data correspond to soils with a low content of organic matter. The soils are situated on sea gravel or eluvium of MBF (PB1 and JD1) contain a large amount of skeletal fraction >3 mm. All studied soils contain around and more than 90% physical sand, i.e. these are sandy substrata.

The processes of transformation of the mineral part in soils are very diverse and this is demonstrated primarily by particle size analysis. In arable land, there is an association between mineral mass and organic matter in varying decomposition state. A prototype of soil structure is formed, which is better expressed the greater the amount of fine soil is (<0.01 mm). The high level of accumulation of biophilic elements, together with the ornithogenic transport of seeds and whole plants, is the reason for the formation of tundra communities in the marine area of Antarctica, which distinguishes this area from other parts of the region. Thus, the ornithogenic factor is crucial for the formation of soils and soil cover in the polar ecosystems on Livingston Island (Abakumov et al. 2008; Abakumov 2010, 2014).

Table 2. Basic chemical characteristics of soils

Location name	Type	pH_{H2O}	TOC, %	N, %	C/N
Playa Bulgara (PB1)	Cryosols Leptic	6.03	0.79	0.09	9.08
Hesperides Point Pluton (HPP2)	Cryosols Histic Hyperskeletic	5.85	0.10	0.01	8.13
Punta Hesperides (PUN-H1)	Cryosols Histic Hyperskeletic	5.82	0.50	0.06	8.09
Johnson Dock (JD1)	Cryosols Leptic Hyperskeletic	6.60	0.52	0.08	6.81
Caleta Argentina (CA1)	Cryosols Leptic Ornithic	5.75	3.47	0.38	9.23

The results analysed in Table 2 show that the studied soils are moderately acidic, and the pH changes in a very narrow range. The analysis shows that the type of vegetation – lichens, mosses or grass formations and the combination between them does not affect the soil reaction. The content of organic carbon defines them as low-humus, with the exception of ornithogenic soil formed under grass tufts and remnants of penguins' vital activity. Humification is manifested in all soils of the Antarctic, where there is organic matter. Nevertheless, humification is accompanied by the formation of an increased amount of fulvic acids with a low proportion of humic substances (Abakumov et al. 2009; Abakumov 2011; Chukov, Abakumov & Tomashunas 2015).

The signs of transformation of the mineral and organic part of the soils are especially well observed in the mezo and micromorphological studies (Figure 7, Photos 1-4). Mezomorphological observations of the soils formed on bare rocks (sampling sites PB1 and JD1) showed, that these were unconsolidated mineral masses where the predominated volcanic particles have dimensions from 1–3 cm to 2–5 mm, and volcanic glass particles are detected. Between the particles, we distinguish dark grey-brown minerals with dimensions of fine and small sand particles (Sokolovska et al. 2015). The soil under moss (sampling sites HHP2 and PUN-H1) showed that the mineral composition was the same as that of the fragmental soil, but in this case, the mass lacks solid structure and was hardened by the moss vegetation the roots (penetrated to 4 cm in depth). The mezomorphological observation of the soil formed under post-ornitogenic environment (site CA1) showed, that the soil is characterized by weak structure. The mineral particles and fine rounded aggregates were tied up with fine roots and to a certain extent – were fastened to each other.

Micromorphological observation of Cryosols shows that the s-matrix is built by porous, well-developed microspaces. The s-matrix represents the material within the simplest (primary) peds or composing apedal soil materials, in which pedological features occur; it consists of plasma, skeleton grains, and voids that do not occur in pedological features other than plasma separations (Brewer, R. 1976). This is important for aeration and rapid temporary accumulation of large amounts of water. In the main mass, the mineral phase prevail, containing a lot of mica, unaffected by transformation, which is an indicator of a low degree of weathering of the mineral part of the soil.

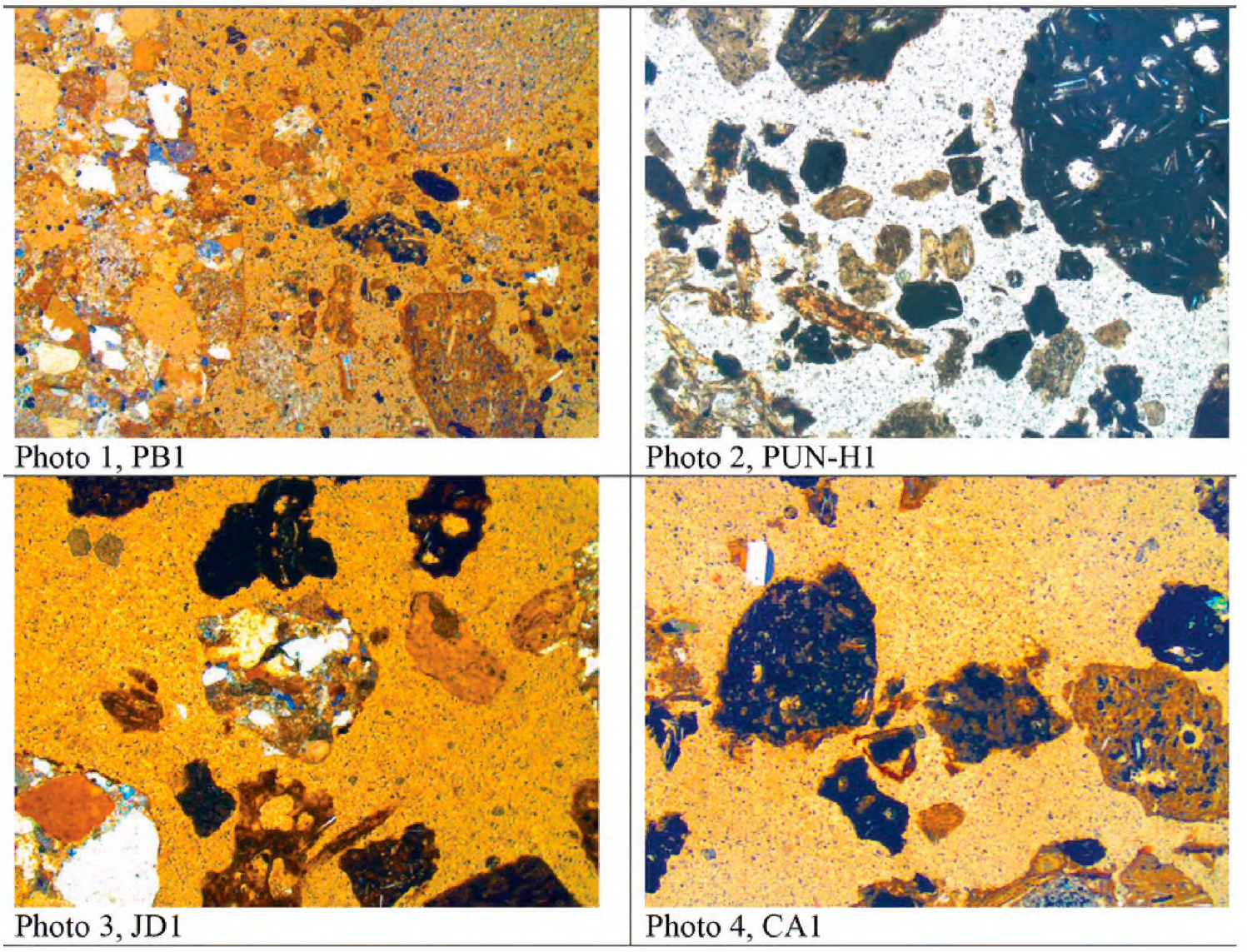

Figure 7. Micromorphological observations of the studied soils

A large amount of finely edged pyroclastic material is observed in the soils developed in the coastal zone and on glacial moraines. Hence, we can observe an evidence for the connection of the processes of soil formation with the pulsating degradation of the glaciers.

Conclusion

Cryosols are the main representative soil type, distributed on the territory of the Bulgarian Antarctic base on Livingston Island. The soils are formed under lichens, mosses, Antarctic grass vegetation and the combination between them. The soil processes in the Cryosols are closely linked to the degradation of glaciers. Taking into account the study area and the polar environment, this soil type is characterized by a low profile with the dominant participation of skeletal and sandy fraction. Fine earth (<1 mm) varies from 2 to 10%, and the ratio between physical sand and physical clay – between 85-95% and 2-10%.

The soils are moderately acidic and the pH is in a narrow range. The process of humification is weak. The organic carbon content is low, except for soils formed under the influence of an ornithogenic factor. Weak and moderately decomposed plant tissues represent soil organic matter. The C/N ratio indicates slow and incomplete transformation of organic residues.

The mezo- and micromorphological observations show a predominance of the mineral phase, weakly affected by weathering processes. Many soil pores and voids are observed, which facilitates water-air and intra-soil exchange during the short Antarctic summer.

Aknowledgements

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